DSN TECHNOLOGY PROGRAM NEWS
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COMMUNICATIONS SYSTEMS ANALYSIS

KA-BAND FOR PLUTO FAST FLYBY

MILES K. SUE

Pluto Fast Flyby is considering using Ka-band (32 GHz) and X-band (8.4 GHz) as its downlink frequencies. X-band has been the communication frequency for most deep-space missions for many years. Ka-band however has a significant telecom advantage over X-band because the higher frequency allows the spacecraft to focus the transmitted RF energy in a smaller beam.

If we could ignore the effects of pointing errors, atmospheric losses, antenna efficiency, and receiver losses, the capacity of a deep space channel would be proportional to $P_T A_T A_R / \lambda^2 r^2$, where P_T is the spacecraft transmitter power, A_T and A_R are the areas of the transmitting and receiving antennas, respectively, λ^2 is the square of the wavelength, and r^2 is the square of the distance from the spacecraft to the receiving antenna. Capacity is the number of bits that can be reliably transmitted per unit time. This means that if all other things were equal, the potential gain going from X-band to Ka-band would be $(32/8.4)^2$, or a factor of 14.5, or 11.6 dB. That is, 14.5 times as much data could be sent in given period of time. This could be used to increase the data rate, or to decrease operations costs by scheduling fewer hours of ground antenna time, or mission planners could choose to use less power for the spacecraft transmitter, or have a smaller spacecraft antenna, or any combination of these things, enhancing, or even enabling, future generations of small, low-cost deep space missions. There are a number of factors that reduce the Ka-band advantage, including lower transmitter efficiency, more severe atmo-

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LAIF SWANSON

Most of the articles in this issue relate to our Ka-band thrust. Ka-band is a higher frequency (32.0 GHz) than the X- and S-bands usually used in deep space, and promises significant performance and cost improvements. These are described in Miles Sue's article "Ka-Band for Pluto Fast Flyby". I recommend that any non-expert read this article first. (Miles leads the Microwave Systems work unit in the Communications Systems Analysis work area.) David Morabito's article on KaAP, the Ka-Band Antenna Performance experiment, describes our studies of Ka-band performance, based on the reception of Ka-band sources; since we currently have no manmade Ka-band sources in deep space, we use planets and quasars. (Dave leads the KaAP experiment.)

Of course we want spacecraft to transmit Ka-band signals so we can determine their usefulness, and we are planning two experiments of this kind: SURFSAT, which will be described in the next issue of the *DSN Technology Program News*, and Ka-Band Link Experimen (KaBLE-II) on Mars Global Surveyor (MGS). MGS will be launched in November, 1996, and will send Ka-band signals for KaBLE-II; Stan Butman, who is also the MGS telecom manager, leads this experiment.

Since the fasterbettercheaper spacecraft of the future need a small, inexpensive, power efficient telecom system, we are looking at the Tiny Transponder, a concept for a faster, cheaper, lighter, and less power-hungry X- and Ka-band transponder.

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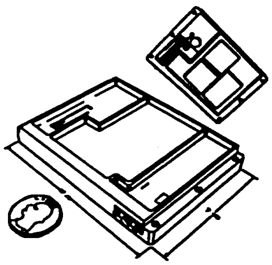


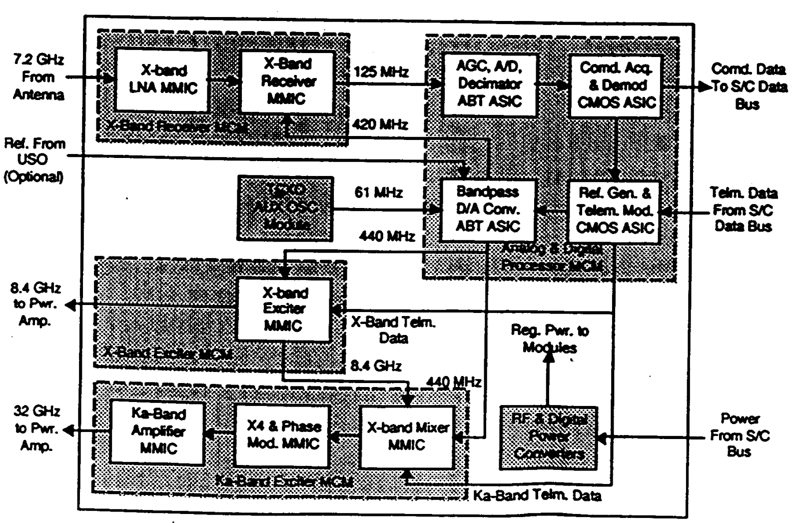
Tiny Transponder

George Zimmerman and Lance Riley

Future deep space missions will require telecommunications subsystems that are smaller, less expensive, and consume less power than those used in today's missions. The most expensive and massive component of the spacecraft radio frequency subsystem is the deep space transponder. The transponder acts on both downlink and uplink data. For downlink data, it receives digital data from the spacecraft's command and data subsystem (CDS), encodes it, modulates it, and passes it on to an external power amplifier for transmission. For uplink commands, the transponder receives the RF signal from the antenna, amplifies, downconverts and demodulates it before passing it to the CDS.

A new, next-generation spacecraft transponder, dubbed the Tiny Transponder, would leap ahead of near-term small deep space transponder designs by having approximately 10% of the mass and volume and consuming 40% of the power of comparable components being flown on the Cassini mission. If funding is initiated in FY96, this transponder would be available for missions starting in the year 2000, with a recurring cost that's less than one-fourth that of the current transponder designs.

The Tiny Transponder will integrate functions currently residing in the transponder (a receiver and coherent downlink exciter), the Command Detector Unit (CDU), which demodulates commands to the spacecraft, and the Telemetry Modulator Unit, which performs convolutional coding and modulates data onto subcarriers for downlink, into one unit roughly the size of a pocket calculator, consuming under 7 watts of power.



This revolution in transponder technology is accomplished by inserting advanced technology from multiple areas. One of the keys to the Tiny Transponder is the use of full-custom integrated circuit technology, both as cutting-edge high-integration-level Monolithic Microwave Integrated Circuits (MMICs) and as mixed-signal silicon Application Specific Integrated Circuits (ASICs). Through the use of full-custom MMIC and ASIC designs, the Tiny Transponder design will be able to reduce the number of parts in the transponder by more than an order of magnitude. The majority of the transponder functions would be implemented in six MMICs and four ASICs, the spacecraft equivalent of the coming generation of wireless personal communications devices.

The Tiny Transponder will be designed in a modular fashion and can be produced with an X-band receiver and X-band and/or Ka-band exciter. (The X-band exciter configuration design will consist of only seven custom chips.) The block diagram shows the X-band receiver and X-/ Ka-band exciter. The gray areas indicate multi-chip modules (MCM) and the boxes in white indicate chips. The chips are labeled as GaAs MMICS, advanced bipolar technology (ABT), silicon ASICS, or complementary metal oxide semiconductor (CMOS) silicon ASICs.

The MMIC devices will incorporate state of the art levels of integration, particularly in the receiver and X-band exciter chips. Each of these chips will integrate about 50 field effect transistors on GaAs to implement mixers, local oscillators, frequency dividers, amplifiers, and power dividers at multiple frequencies. MMIC designs at this level of integration are just becoming available as a result of the Advanced Research Project

Agency (ARPA) MIMIC program investment of approximately a half billion dollars. The large scale integrated MMICs for the Tiny Transponder will be designed and developed through a partnership between JPL and industry.

Together, four ASICs will be required to perform the baseband and IF processing in the Tiny Transponder. These four ASICs are divided into (1) gain control and digitization, (2) carrier acquisition and demodulation, (3) reference generation and telemetry modulation, and (4) digital-to-analog conversion. This division of functions allows the use of appropriate integrated circuit processes and techniques to maximize the performance and minimize the risk in the silicon ASIC designs. While the analog-to-digital and digital-to-analog conversion ASICs will be produced with a high-speed bipolar ASIC process, the bulk of the digital processing will be performed in the other two chips that are fabricated from the more power-efficient CMOS technology.

The baseband ASICs will make use of digital receiver and algorithm technology developed for ground systems by the DSN Technology Program in the Network Signal Processing work area. Open-loop acquisition for digital receivers via fast Fourier transforms (FFTs) has been demonstrated in the advanced ground receivers. This technology in the Tiny Transponder design will simplify ground operations by eliminating the need to sweep the uplink carrier on acquisition.

Reduced-complexity numerically-controlled oscillator (NCO) algorithms developed for ground frequency synthesis make direct digital synthesis of the receiver local oscillator and exciter reference possible, eliminating the need for voltage-controlled oscillators, which require tuning and extra circuitry to correct for frequency drifts during the flight. Other novel signal processing structures were less direct spinoffs of investigations carried out in the DSN Technology Program, such as delta-sigma bandpass D/A converters (DACs) that convert the NCO outputs to analog form. These DACs are related to circuits considered for use in the ground frequency synthesis application. Components of the MMICs to be used in the Tiny Transponder have been demonstrated in an Small Business Innovative Research (SBIR) program under JPL sponsorship. MMICs of this type, although not as highly integrated, have been demonstrated in X-band receivers and X-band and Ka-band exciters developed under the DSN Technology Program.

To date, a design study on the Tiny Transponder that involved industry in the process to determine the feasibility of the design has been successfully completed. Funding to develop the transponder is expected in the near future.

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A team led by William Rafferty, Deputy Manager of Section 339, Lance Riley, manager of our Advanced Spacecraft Telecom Systems work area, and George Zimmerman, manager of our Network Signal Processing work area, has recently done a study of this concept, which is described in their article.

Some communications ideas are independent of transmission frequency; one of these is error correcting codes. Error correcting codes add redundancy in a controlled way, so that channel errors can be caught and fixed. A good error correcting code will do much more than make up for its own overhead – theory tells us that a fixed amount of energy can allow transmission of about thirteen times as much coded information with a bit-error-rate of 10^{-5} as uncoded. Coding theorists look for codes that come close to this theory. Several years ago, our program found the advanced codes to be used on Galileo, Pathfinder, and Cassini; in this issue Fabrizio Pollara describes a new coding system which gains even more, with substantially less decoding complexity. This work was done in the Communications Systems Analysis work area, which Fabrizio manages.

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